venience, while American Fork Canyon sent a flood of mud and rocks onto the adjacent grain fields and over the roadway, near Alpine, Utah County. At Mount Emmons, some fields and roads were flooded and a cow drowned; and near Moroni, Sanpete County, highways, fields, and crops suffered damage in excess of $500. The mountain highway between Richfield and Fish Lake, Sevier County, was closed by mud washes, necessitating long detours. The heaviest earth wash on this date came out of Snowslide Gulch in Provo Canyon, Utah County, just above Donnan's Upper Falls Resort, where about noon a run began which in a short time laid down a body of mud that extended entirely across the canyon and buried the highway from 1 to 8 feet deep for a distance of nearly 500 feet. Provo River was dammed up to a height of 2 feet above the railroad tracks, and a power company water flume was considerably damaged. Automobile traffic was towed through the pool of water for two weeks, though drag lines lowered the water level away from the railroad in a few days.

Other deluging rains on Wednesday, August 13, augmented the flood conditions in all the damaged areas in Davis, Salt Lake, Tooele, and Utah Counties. The interurban electric railroad near Farmington was covered with mud again, and the track was undermined by running water just north of town. The highway excavation through the Ford Creek flood was so badly refilled, the project was abandoned and a corduroy detour constructed over the débris to one side. New mud washes in Provo Canyon hampered the work of repairing the highway, and marooned several automobiles between the floods of mud. A second flood of mud ran through the premises of the Arthur ore concentrating mill near Garfield, silting the works extensively with mud, which can be removed from many places only at heavy expense. A large concrete highway bridge over Price River between Helper and Price, Carbon County, was undermined and broken down, the flood waters also breaking two water pipe lines. Silver City, Juab County, suffered from a rush of water through the village, while over toward Elberta, Utah County, heavy floods tore their way down Big Government Canyon, damaging a bridge and several miles of railroad. Three cottages were carried away at the Apex mine, and the highway and a considerable acreage of farming land were overflowed, largely with mud, near Elberta.

Though measurements of rainfall at substations in the vicinity of flooded areas appear to bear no very consistent relation to the magnitude of the various floods, it is perhaps significant that the total rainfall for the State during August was about two and one-half times the normal amount.

CLIMATIC CYCLES

By PROF. ALBERT W. GILES

[University of Arkansas, Fayetteville, Ark., August 1, 1930]

In the MONTHLY WEATHER REVIEW of December, 1929, Doctor Marvin describes a simple apparatus devised to illustrate graphically cycle recurrences with variable length of both period and amplitude. The device, which is designated an "harmonic analyzer," possesses elements which may be readily made continuously and irregularly variable during its operation, resulting in a curve representing any desired irregularity in period and amplitude of the cycles composing the sequence illustrated by the curve. An equation by Fujiwhara is cited by Doctor Marvin as the first attempt to analyze mathematically the problem of periodicities with variable length and amplitude. In concluding his article Doctor Marvin very properly advises that "we should not require one mechanical model of this kind to represent all the details of a complex periodic curve, but rather the problem is to find a comparatively few elements having individual and separate variable amplitudes and periods of their own, which in combination produce the complex curve nature gives us."

The continuous changes marking the progress of climate through the ages would seem admirably adapted to representation as a curve involving cyclical recurrences possessing variable length of both period and amplitude. But climate is a composite consisting of several elements each of which is irregularly variable, and variation in one need not and frequently does not coincide with variation in the other elements. Hence the superposition of the curves representing the histories of the several climatic elements upon a grid or other graphic base would only result in a network characterized by the absence of harmonic or mathematical precision.

Even the graphic representation of a single element of climate is difficult, particularly when the curve is extended backward to illustrate the history of that climatic element in its progress through geologic time. The difficulty, of course, may be largely overcome by considering only the contemporary history faithfully recorded instrumentally, but after all the progress of climate through the ages is an interesting and vital part of climatology, a part that may throw light upon present climatic conditions, just as the history of organisms through the ages is a part of biology and an aid to the biologist in his interpretation of biologic factors, as, for example, contemporary distribution of organisms, the origin of vestigial structures, and evolution.

The essential elements that comprise the composite called climate are temperature, pressure, wind direction and velocity, humidity, cloudiness and sunshine, amount and kind of precipitation, and types of storms. A detailed description of the climate of a locality or a region would include not only the daily, monthly, seasonal, and annual averages for each of the climatic elements, but also indicate significant daily, monthly, seasonal, and annual departures from the averages. Obviously, the more detailed the description of the climatic elements, the larger the number of climatic provinces that may be differentiated. For the United States 10 climatic provinces are recognized and described by Ward in his Climates of the United States. On the other hand, a map recently published describes the "climates" of Maryland and Delaware, representing a very refined classification. But using the refinement in classification comparable to that of Ward it is possible to recognize probably 25 or more climatic provinces in North America.

In going back into geologic time the evaluation of climatic elements becomes increasingly difficult. As a result, temperature is the element usually considered, the others being wholly neglected or their importance inadequately summarized. It is highly probable that certain elements of climate, such as humidity, average sunshine, and average cloudiness, can never be more than roughly estimated for most of the geological periods; on the other hand, it is reasonably certain that the climates of the geologic past will be eventually much more thoroughly understood in details and in duration than they now are.

Again, the interpretation of geologic climate suffers from broad and vague generalization. Land areas of great extent in latitude and longitude are often considered as possessing one type of climate persisting through spans of millions of years. The climate of geologic periods is frequently summarized in standard texts of historical geology as "mild from pole to pole," a generalization often based on the distribution of marine faunas. Such statements are vague, inaccurate, and meaningless. Land masses of significant dimensions must always have experienced a variety of climates, and as knowledge of paleogeography increases it will be possible eventually to block out roughly climatic provinces of the past.

Temperatures alone is the most significant climatic element and in turn exerts a marked influence upon the other climatic elements. Although the march of temperature through the ages is known only in a very broad and general way, yet it is possible to attempt the construction of a curve, following the suggestion of Doctor Marvin, representing its fluctuations during the progress of time. Possibly the simplest method of approach to the problem is the plotting of a curve representing departures from the mean annual temperature for a station whose instrumental records go back over a considerable period of time. For this purpose Little Rock, whose temperature record is known for a half century, has been selected as typical. The annual means have been supplied by Mr. Cole, meteorologist in charge of the station. The average annual temperature of Little Rock is 62.1° F., based on a record of 50 years, of which 23 years show a positive departure and 26 years show a negative departure, the greatest positive departure being 1.9° F and the greatest negative 2.3° F. The results are graphically illustrated in top curve in Figure 1. The resulting curve is obviously asymmetric and illustrates very well cyclical recurrences possessing variable length of both period and amplitude. The effect of the 11-year sunspot cycle, the Brückner cycle, and other possible cycles which should be reflected in a rhythmic periodicity in the curve is apparently masked by temperature effects produced by other factors.

Since temperature is an irregularly fluctuating climatic element continuously in operation, it is possible theoretically to plot its trend through all four sets of temperature cycles as a single curve, but practically there are serious difficulties in the way of its accomplishment. These difficulties arise from the brief duration of the tertiary and quaternary cycles as compared with the enormous duration of the primary cycles. To depict accurately the former cycles on a curve showing the primary and secondary cycles the drawing would necessarily be of such dimensions as to be unwieldy.

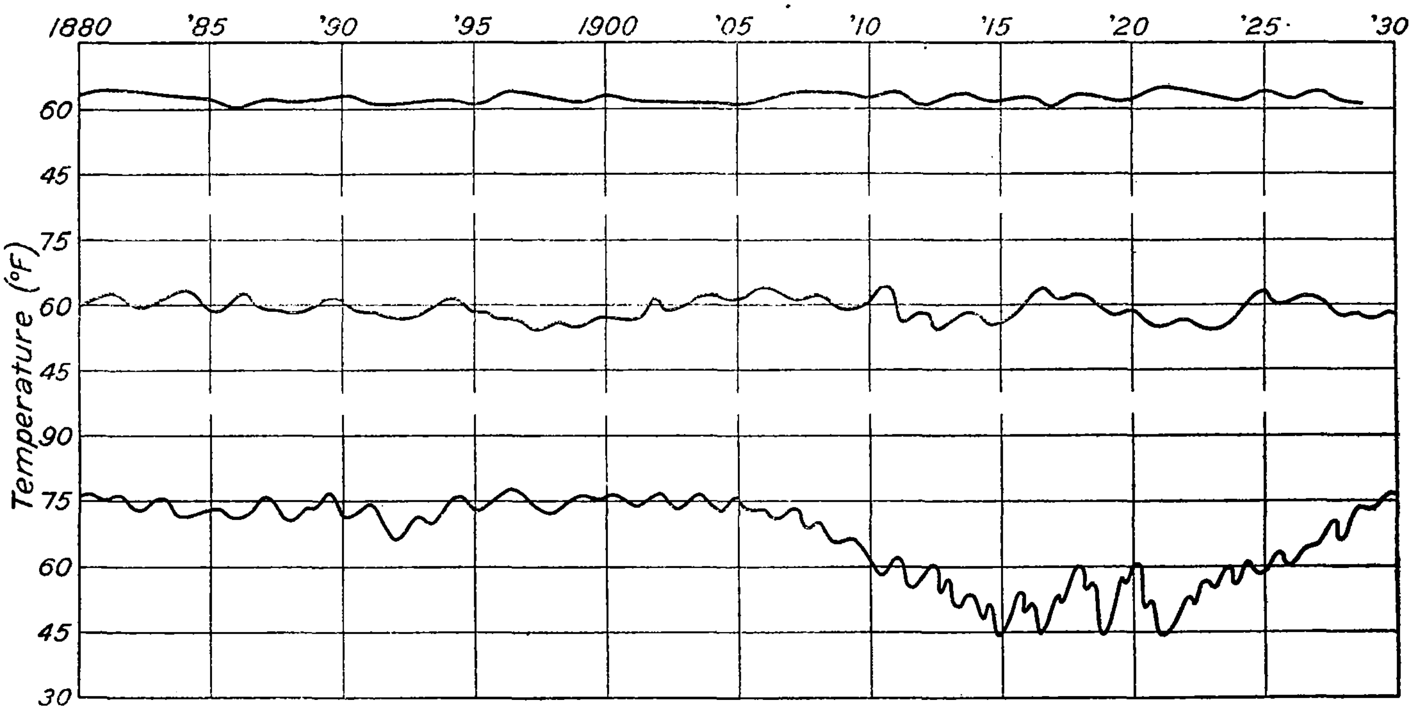

FIGURE 1. *Top curve.*—Diagrammatic representation of the character of temperature pulsations affecting localities within brief periods of time, designated as quaternary cycles. Length of time represented by curve is 50 years

Middle curve.—Diagrammatic representation of the character of temperature pulsations affecting areas of regional extent within the historic period, designated as tertiary cycles. Length of time represented by curve estimated in terms of thousands of years.

Bottom curve.—Diagrammatic representation of the character of temperature pulsations affecting areas of world-wide and hemispherical extent during the progress of geologic time, designated as primary and secondary cycles. Length of time represented by curve estimated in terms of tens of millions of years. Secondary cycles are superposed on a primary cycle.

In view of the difficulty of executing a curve showing the range of the single climatic element, temperature, through the ages it would seem almost hopeless to attempt representation of all the climatic elements, frequently divergent in their intensity, as a single curve. And while it may seem desirable to represent for any region or locality the march of the element, temperature, or the march of the composite, climate, through geologic time in the form of one or more mathematical equations, yet so far this does not seem possible of accomplishment. Such equations, if formulated, must include one or more variables which would tend to minimize their value. The time will probably never come when all natural phenomena can be reduced to mathematics, even if that were desirable.

Curves as Figure 1 (top curve) may be constructed illustrating the daily, monthly, or seasonal march of temperature for a locality or a region. Such curves would also exhibit a similar uneven, arhythmic trend. The superposition of these curves upon the curve of Figure 1 would greatly complicate that curve, but by using a sufficiently large scale their accurate representation is possible. In this way the march of temperature would be faithfully portrayed, but the resulting curve in its physical aspect would differ in no essential particular from the arhythmic curve of Figure 1. (Top curve).

Since the march of temperature through geologic time is continuous, minor fluctuations of the small amplitude and brief duration just described and illustrated in Figure 1 (top curve) may be designated as quaternary cycles, the effects of which involve areas of limited extent. The temperature pulsations of areas embracing large parts of the earth, however, are to be measured in terms of longer sequence, as decades or scores of years, or even centuries, as the cold fourteenth century. The fluctuations nevertheless are aperiodic, the span of cold years differing in length from the span of warm years, and succeeding spans of cold or warm years likewise being of unequal intensity as well as of unequal duration. Figure 1 middle curve illustrates the trend of temperatures through the centuries, the pulsations of which are familiar within the historic period. The middle curve of Figure 1 differs in no essential respects from the top one of Figure 1 except that the amplitude of the pulsations is larger, their duration longer, and the temperature effects are experienced over larger areas of the earth's surface, as regions or large parts of continents. Such fluctuations in temperature may be designated as tertiary cycles.

Going back into geologic time a similar temperature fluctuation is discernible, but the pulsations recognized have been of much longer period and greater amplitude when compared with the pulsations within the historic period. Warm periods have alternated with cold periods, the warm periods continuing apparently much longer than the cold periods, so that it is customary to regard the former condition as typical of earth climate through geologic time. These major fluctuations in climate are of world-wide extent, the warm span of the cycle possessing average world temperature of 15° to 20° F. above that of to-day (59° F.), with weaker zonal and seasonal contrasts as compared with the present. The cold span of the cycle was normally of briefer duration than the warm span with world temperature 10° to 15° F. below the average temperature of the present and with marked seasonal and zonal contrasts, high temperature gradients and vigorous atmospheric circulation very similar to the condition of to-day.

There may be some question as to whether the temperature departures from the present mean for the world (59° F.) during the warm and cold periods were of the magnitude just given, but the distribution of animals and plants indicate that during the warm periods equable conditions with weakened zonal contrast have extended from the equatorial region far northward and southward, with climate more genial than the present in temperate and polar regions. During the cold periods glaciers descended to low altitudes on the uplands of the whole world, and snow and ice mantled large areas of the earth's surface outside of polar regions. The temperature of tropical regions was lowered, and animals and plants withdrew equatorward, became extinct, or developed resistance by adaptation to rigorous environmental conditions.

The major fluctuations in temperature just described are the most significant climatic features in the history of the earth. They have notably and repeatedly influenced the life of the earth, and have left the record of their duration in widespread deposits. In the effort to explain the causes of these repeated and pronounced major fluctuations much has been written, but the problem still awaits an adequate, convincing, and complete explanation. The major fluctuations in temperature during the progress of geologic time with duration to be measured in terms of millions and tens of millions of years may be designated as primary cycles. They are graphically represented in the bottom curve of Figure 1.

The primary cycles in turn are subject to long-range, irregular fluctuation. For example, during the cold periods glaciers have repeatedly advanced and retreated; thus during the "ice age" through which North America has recently passed glaciers of regional proportions accumulated and melted five successive times, the intervening interglacial epochs being of unequal duration, and some of them possibly with higher average temperature than that of the present. The duration of each of the glacial and interglacial epochs is to be measured in terms of hundreds of thousands of years. The Permo-Carboniferous glaciation of low latitudes, chiefly in the Southern Hemisphere, was likewise characterized by a succession of ice advances alternating with retreats and disappearance of the ice over large areas, indicative of fluctuating temperature and possible changes in amount and distribution of precipitation and in geographic conditions.

Although the evidence is not so conclusive, yet it suggests that the long warm periods of geologic time have likewise been cyclic with colder, but not glacial, spans of time alternating with the warmer spans. These spans also are long, to be measured in terms of tens of thousands or hundreds of thousands of years, and all of a periodic or unequal duration, succeeding cold pulsations unequal in intensity and in length, succeeding warm pulsations unequal in intensity and in length, and the cold and warm spans likewise unequal in their respecitve durations. These pulsations of temperature may be designated as secondary cycles with influence world-wide or hemispherical in extent. They are diagrammatically illustrated in Figure 1 (bottom curve) in which they have been superposed upon a major or primary cycle.

It is thus possible to differentiate four sets of cycles characteristic of the march of temperature during the known history of the earth, basing the differentiation upon the respective relative lengths and amplitudes of the cycles. The primary cycles are of greatest amplitude and longest duration with world-wide effects, the secondary cycles are of smaller amplitude and briefer duration, with world-wide or hemispherical effects, the tertiary cycles are of relatively small amplitude and brief duration geologically, familiar within the historic period, with regional effects, and the quaternary cycles, familiar within the lifetime of individuals, are of very small amplitude and of very brief duration, and of local extent. The arhythmic and irregular character of the pulsations of any one of the sets of cycles is well illustrated in the curve depicted by Doctor Marvin.